

Incoherent diffraction as a probe of fluctuations

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With B. Schenke, T. Lappi and R. Venugopalan

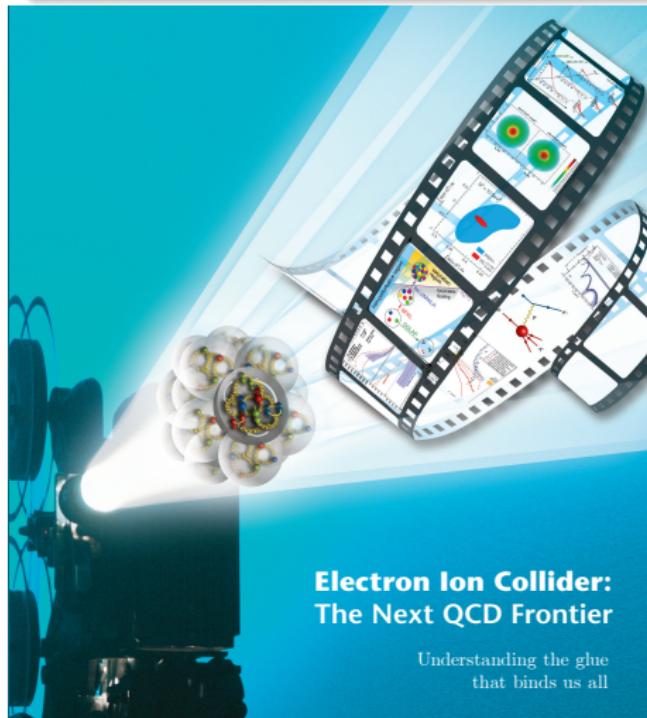
Brookhaven National Laboratory

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Introduction

One of the key EIC questions

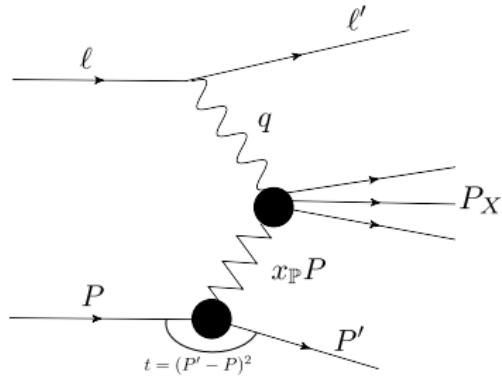
How are the quarks and gluons distributed in space inside the nucleon?



Diffractive processes:

- Spatial density profile
- **Density fluctuations**

Diffraction at an EIC



Diffractive events: no exchange of color charge

- Target remains intact: *coherent diffraction*, small $|t|$.
Probes average distribution of gluons.
- Target breaks up: *incoherent diffraction*, larger $|t|$.
Sensitive to fluctuations.

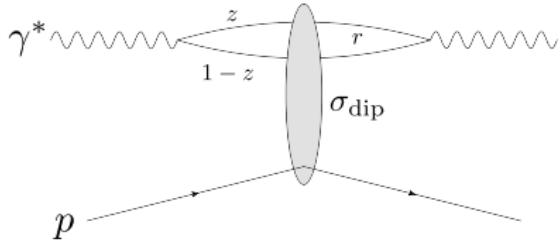
Target: proton or nucleus

Vector mesons from the CGC

CGC: Dipole-proton cross section

$$\sigma_{\text{dip}}(x, r, \Delta) = 2 \int d^2 b e^{ib \cdot \Delta} N(r, x, b)$$

Universal dipole amplitude N



- Exclusive diffraction:

$$\frac{1}{16\pi} \left| \int d^2 r dz \Psi^* \Psi^V(Q^2, r, z) \sigma_{\text{dip}}(x, r, \Delta) \right|^2$$

- Total $\gamma^* p$ (DIS):

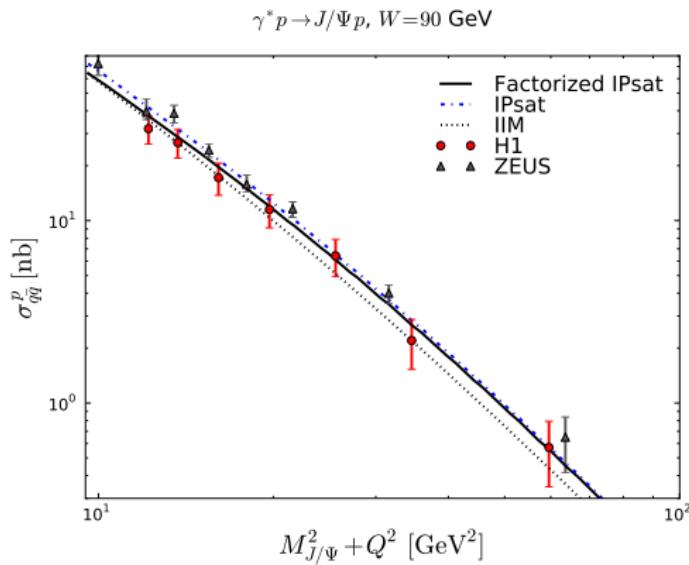
$$\int d^2 r dz |\Psi^\gamma(Q^2, r, z)|^2 \sigma_{\text{dip}}(x, r, \Delta = 0)$$

- Inclusive particle production (pp, pA):

$$\sim x g(x, Q^2) \int d^2 r e^{ir \cdot p_T} [1 - N(r, x)]$$

- + many other processes

Baseline: HERA



T. Lappi, H.M., arXiv:1011.1988

Dipole model calculations are in good agreement with the HERA data.

Dipole-proton scattering: IPsat model

An impact parameter dependent dipole amplitude

$$N(r, x, b) = 1 - \exp \left[-\frac{\pi^2}{2N_c} \alpha_s x g(x, \mu^2) T_p(b) r^2 \right]$$

- Fit to HERA data (F_2): initial condition for the DGLAP evolution of $xg(x, \mu^2)$ (Kowalski, Teaney 2003; Rezaeian et al, 2013)
- Proton profile T_p : Gaussian, width B_p

$$T_p(b) = -\frac{1}{2\pi B_p} e^{-b^2/2B_p}$$

Part 1. Fluctuating nucleus

Coherent and incoherent diffraction

Diffraction off the nucleus:

Generalize IPsat model $T_p(b) \rightarrow \sum_{i=1}^A T_p(b - b_i)$:

- Coherent diffraction: nucleus remains intact

$$\frac{d\sigma^{\gamma^* A \rightarrow VA}}{dt} \sim \langle |\mathcal{A}(x, Q^2, t)|^2 \rangle$$

- Incoherent, nucleus breaks up: variance

$$\frac{d\sigma^{\gamma^* A \rightarrow VA^*}}{dt} \sim |\langle \mathcal{A}(x, Q^2, t) \rangle|^2 - \langle |\mathcal{A}(x, Q^2, t)|^2 \rangle$$

- Quasielastic = coherent + incoherent

$$\frac{d\sigma^{\gamma^* A \rightarrow V(A^* + A)}}{dt} \sim |\langle \mathcal{A}(x, Q^2, t) \rangle|^2$$

$\langle \rangle$ = Average over nucleon positions.

Incoherent calculated in T. Lappi, H.M., arXiv:1011.1988

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Focusing on central events

Goal: probe large- Q_s part of the nuclear wave function

T.Lappi, H.M., R. Venugopalan, PRL 114, 082301



Incoherent diffraction: largish momentum kick is localized on a transverse plane in a nucleon-size area

A nucleon in the nucleus receives a large momentum kick

- Scatters off other nucleons on its path out
⇒ more “ballistic nucleons” in central events ⇒ centrality estimator

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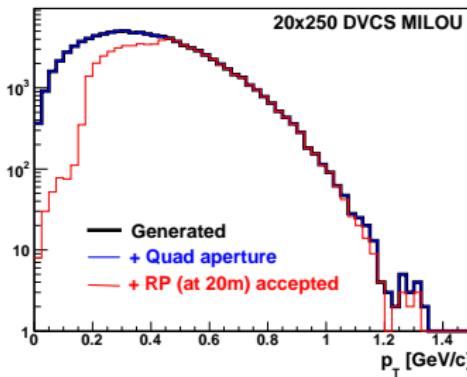
2nd possible component in the emitted nucleon spectrum

- *Evaporation nucleons*: excited nucleus decays
⇒ Thermal spectrum in the rest frame, different kinematics

Measuring ballistic protons

Incoherent diffractive J/Ψ production: p_T kick ~ 1 GeV.

- Ballistic protons can be measured in the Roman pots



EIC acceptance in e+p, good in $p_T \sim 0.5 \dots 1$ GeV!

Note: ballistic neutrons are indistinguishable from thermal at ZDC

Example: centrality in incoherent vector meson production

Study the centrality dependence of $\gamma^* A \rightarrow V A^*$
 $V = J/\Psi, \rho, \phi, \dots$

Double ratio

Study Q^2 dependence of incoherent production ratio

$$\frac{\sigma(\gamma^*A \rightarrow V_1 A^*) / \sigma(\gamma^*A \rightarrow V_2 A^*) \Big|_{\text{central}}}{\sigma(\gamma^*A \rightarrow V_1 A^*) / \sigma(\gamma^*A \rightarrow V_2 A^*) \Big|_{\text{minimum bias}}}$$

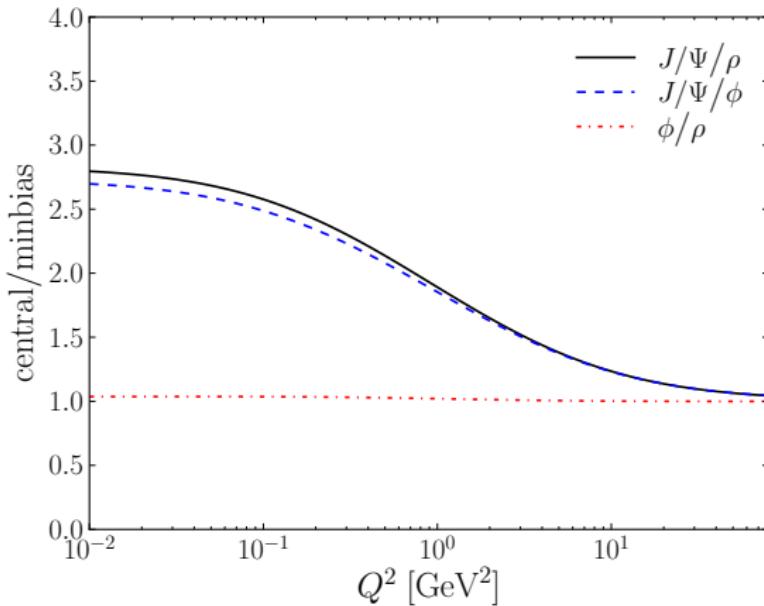
Consider two centrality classes

- Central (on average more ballistic protons): $b = 0$
- Minimum bias

Many theory uncertainties cancel in this ratio.

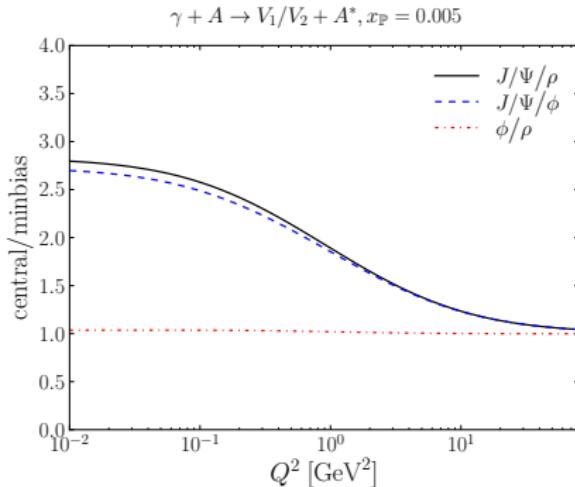
Double ratio

$\gamma + A \rightarrow V_1/V_2 + A^*, x_{\mathbb{P}} = 0.005$



T. Lappi, H.M., R. Venugopalan, PRL 114, 082301

Why enhancement at low Q^2 ?



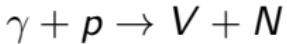
T. Lappi, H.M., R. Venugopalan, PRL 114, 082301

J/Ψ is much heavier (smaller), so at small Q^2 :

- For ρ and ϕ production $r^2 Q_s^2 \gtrsim 1$ at both central and minimum bias, cancel in double ratio
- Double ratio is central-to-minimum bias ratio for J/Ψ
 $\sim Q_{s,\text{central}}^4 / Q_{s,\text{min. bias}}^4$

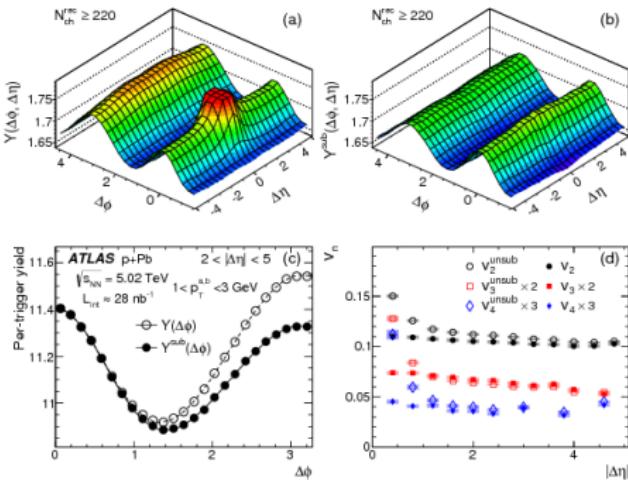
Part 2. Fluctuating proton

Fluctuating proton



Incoherent diffraction off the proton: probe proton shape fluctuations

- Also needed for applications, e.g. to describe collectivity in pA?



ATLAS, arXiv:1409.1792

Constraining proton shape

B. Schenke, H.M. in progress

Example/toy model: consider a proton where color charge density is distributed around 3 “valence quarks”:

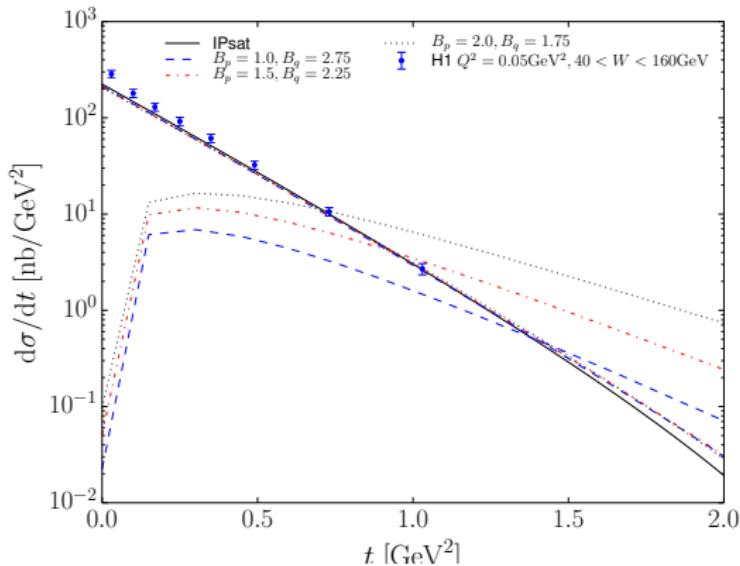
- Sample quark positions from Gaussian distribution, width B_p
- Set quarks to have Gaussian width B_q
- Use IPsat model to calculate coherent and incoherent diffractive J/Ψ production

Our proton = 3 overlapping hot spots, constrained by F_2 data.

Cohernet and incoherent spectra



$$Q^2 = 0, W = 100\text{GeV}$$

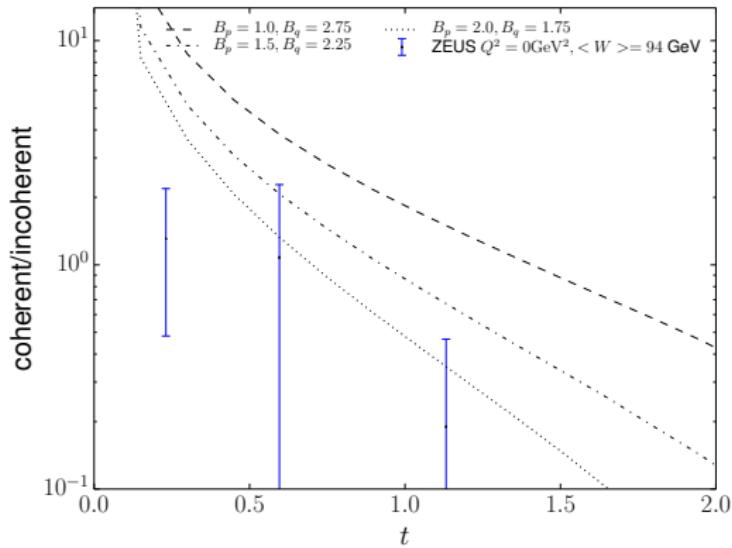


HERA coherent data does not constrain fluctuations

- Incoherent spectra are very different

HERA proton dissociative data

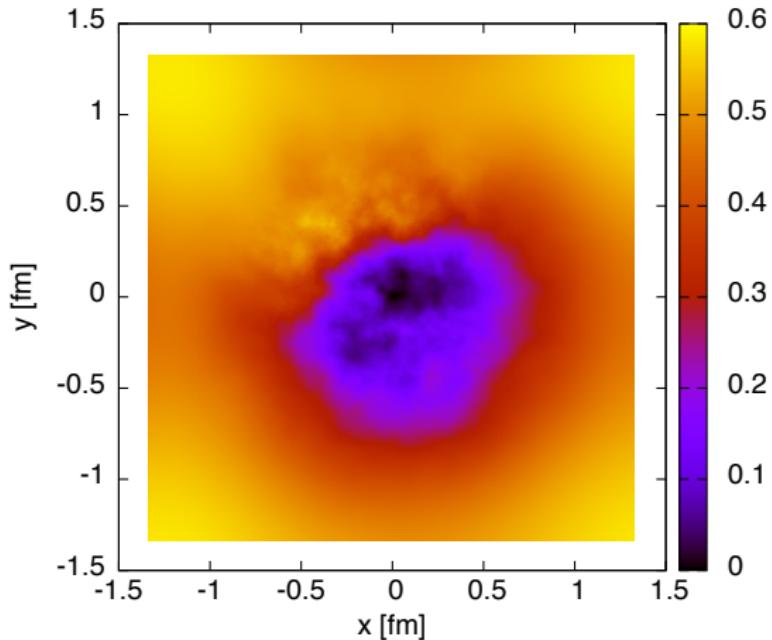
$Q^2 = 0, x = 0.001, W \sim 100\text{GeV}$



Incoherent measurements have discriminating power.

Data: ZEUS hep-ex/9910038

Proton is a quantum mechanical object: IP-Glasma



Trace of Wilson lines $1 - \frac{1}{N_c} \text{Tr } U(0)U^\dagger(x, y)$ from the MV model
Shows the degree of fluctuations

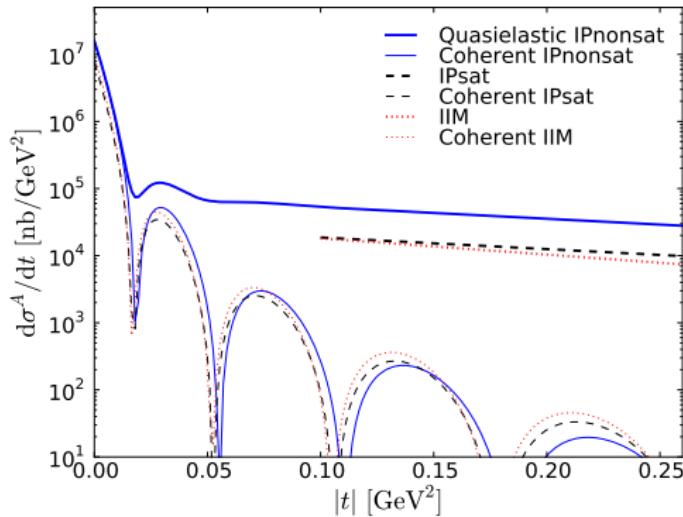
Conclusions

- Incoherent diffraction can be used to probe density *fluctuations*
- Diffraction with nuclear targets: ballistic proton multiplicity in the Roman pot detector \Leftrightarrow centrality
 - Triggering on highest proton multiplicities allows us to probe large- Q_s part of the nucleus wave function
- Incoherent diffraction with proton targets: EIC could constrain proton shape fluctuations
 - Work in progress: more realistic description of the color charge fluctuations: IP-Glasma framework

Backups

$\gamma A \rightarrow J/\Psi A$

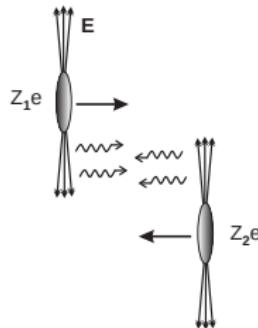
$A = 197, Q^2 = 0 \text{ GeV}^2, x_{\text{p}} = 0.001$



T. Lappi, H.M., arXiv:1011.1988

- Coherent spectra $\sim \text{FT}$ of average density profile
- Incoherent process dominates at large $|t|$
- Incoherent cross section is also sensitive to saturation effects.

Before EIC: ultraperipheral AA collision



nucl-ex/0502005

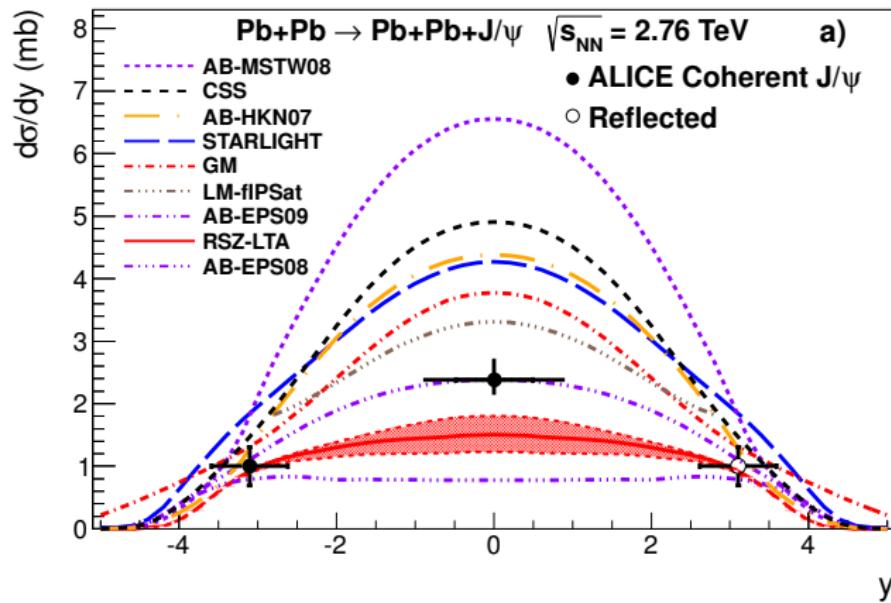
$b \gtrsim 2R_A$: strong interactions suppressed, nucleus creates photon flux $n(\omega)$
 $\sigma \sim n(\omega)\sigma^{\gamma A}(\omega)$

Probes gluons with $x = M_V e^y / \sqrt{s}$

- Forward LHC: $x \sim 0.02$ and $x \sim 10^{-5}$.
- Midrapidity LHC: $x \sim 10^{-3}$

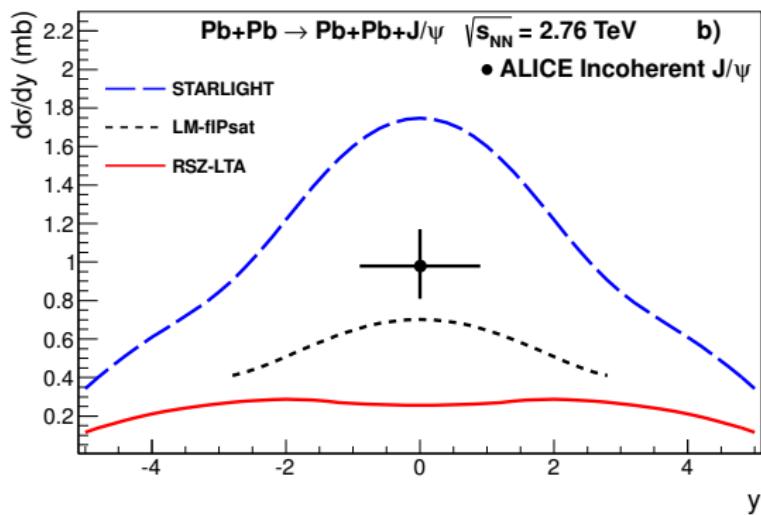
Dipole model is valid only at $x \lesssim 10^{-2} \Rightarrow$ at LHC limit $y \lesssim 2 \dots 3$.

Coherent diffraction, model comparison



Probes average gluon density, models with shadowing/saturation favored.

Comparison of predictions (incoherent diffraction)



Data and other models: ALICE, arXiv:1305.1467

- IPsat calculation: fluctuations from Woods-Saxon distribution
- Simultaneous description of coherent and incoherent data is needed!